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A monthly survey of programs and findings of the International Geophysical Year and International Geophysical Cooperation-1959 as related primarily to United States programs

Meteorological Studies in the Antarctic

The following report is based on a paper presented by Gordon D. Cartwright, Coordinator of International Activities, US Weather Bureau, at the IGY Symposium of the 125th Annual Meeting of the American Association for the Advancement of Science, Washington, D. C., December 29–30, 1959.

The great expansion of meteorological observational facilities in the Antarctic during the IGY has resulted in much new knowledge of weather patterns and of the general atmospheric circulation in this remote, previously little-known region of the earth. This new knowledge represents a substantial beginning to a full understanding of Antarctic and Southern Hemisphere weather and climate.

The important role played by weather and climate in the modification of continents, largely through erosion processes, is well known. In the Antarctic, however, there exists a large, continent-sized region whose present configuration and broad features are more directly the result of weather and climate than of any other factor. Moreover, its subsequent modifications are likely to stem primarily from climatic changes. Thus, an additional challenge is presented to meteorologists to assist in unravelling Antarctic physical history.

Scope and Organization of Program

The meagre observations of earlier Antarctic expeditions, scattered widely both in time and space, hinted at strange weather phenomena not observed in other parts of the world—mysterious pressure waves, baffling suddenness of Antarctic storms, great persistence of hurricane-force winds in some areas, extremely low pressures over long periods during the year, and others.

Basic data were needed to provide the answers. Hence, in spite of the uniqueness of the setting, well-tried kinds of measurements dominated the thinking of IGY planners. As a result, standard synoptic weather observations were made from representative points throughout the Antarctic.

Some 50 IGY stations made regular observations of surface weather at least four times a day. This represents a minimum of 100,000 observations scattered over the continent during the 18-month IGY period. Addition of twice-daily upper-air soundings at 16 stations to an average height of about 20 km—totaling over 300,000 discrete observations at various levels—further enlarges the scope of the data. Added to these are observations of solar radiation received at the surface, made at 28 stations, and data from micrometeorological studies.

Even this mass of information provides only a scant measure of the complexity of the immense processes at work in such a fickle medium as the lower atmosphere. However, these observations have enabled meteorologists, for the first time in history, to construct charts showing broad circulation patterns at various atmospheric levels

above the Antarctic. (Unfortunately, the virtual absence of similar observations over the sub-Antarctic oceans handicaps efforts to link these circulation patterns with those of the temperate regions of the Southern Hemisphere. Filling this gap will be one of the important tasks of the post-IGY years.)

Some Preliminary Results

Analyses of data thus far suggest that Antarctic weather can probably be explained by the same basic relationships existing elsewhere over the globe.

Continental-Oceanic Exchange: It seems clear that a great continental-oceanic exchange of air goes on in the Antarctic throughout the year, but with increased intensity during the winter. This exchange is intimately related to the complex system of low-pressure areas coursing around the continent, about 300 mi off its edge.

The atmospheric circulation resulting from these pressure systems forces warm, moist air at intermediate and higher levels to rise up over the edges of the continent and penetrate far into the interior. This process produces much of the snowfall over the continent. Above the high interior plateau, the air is cooled, eventually becoming part of the relatively stagnant, high-pressure areas predominating over the plateau, especially in East Antarctica. As it settles, the frigid air moves, partly by gravity flow and partly as a result of the general distribution of atmospheric pressure, back down the slope and is again caught up in the low-level circulation of the belt of cyclones circling the continent.

While this is now an accepted description of the fundamental weather processes prevailing over both polar regions, IGY programs have for the first time given a factual basis to the Antarctic picture.

Storm Tracks: The day-to-day preparation of synoptic weather charts for most of the Antarctic during the IGY has brought out two important facts: 1) storms seldom penetrate into the high interior of East Antarctica; 2) storms frequently cross the continent over what may be a great continental trough stretching from the Ross to the Weddell Sea.

When these facts are considered together they suggest that the pole of Antarctic circulation is some distance from the geographic South Pole, just as is the main mass of the continent itself. This single conclusion, elaborated by much more data, can be of great significance to forecasting for Southern Hemisphere countries, especially Australia and South America. The further observation that the major storm tracks seem to divide at the Ross Sea area, some continuing over the South Pacific and others crossing Antarctica, however, somewhat complicates the picture for South America. This may be one of the most significant features of Antarctica circulation brought to light by the IGY Antarctic meteorological program (see Fig. 1).

The tendency of low-pressure areas to develop or stagnate in the great Antarctic embayments of the Ross and Weddell Seas was already postulated before the IGY began. Much more is now known about the extent of these features, which may resemble their Northern Hemisphere counterparts—the semi-permanent lows in the Gulf of Alaska and near Iceland.

The existence of the persistent area of high-pressure air over the high plateau of East Antarctica was also postulated prior to the IGY. This picture is now supported not only by the complex of weather data taken at a number of points in East Antarctica but also by the discovery of a vast area of fluffy snow in this central highland region of the polar plateau; the snow must have fallen under conditions of light winds over long periods of time.

The extent to which these features of the Antarctic circulation are exclusively Antarctic conditions, rather than a result of the broader geographical circumstances of the entire Southern Hemisphere (e.g., the relative positions of major land masses)

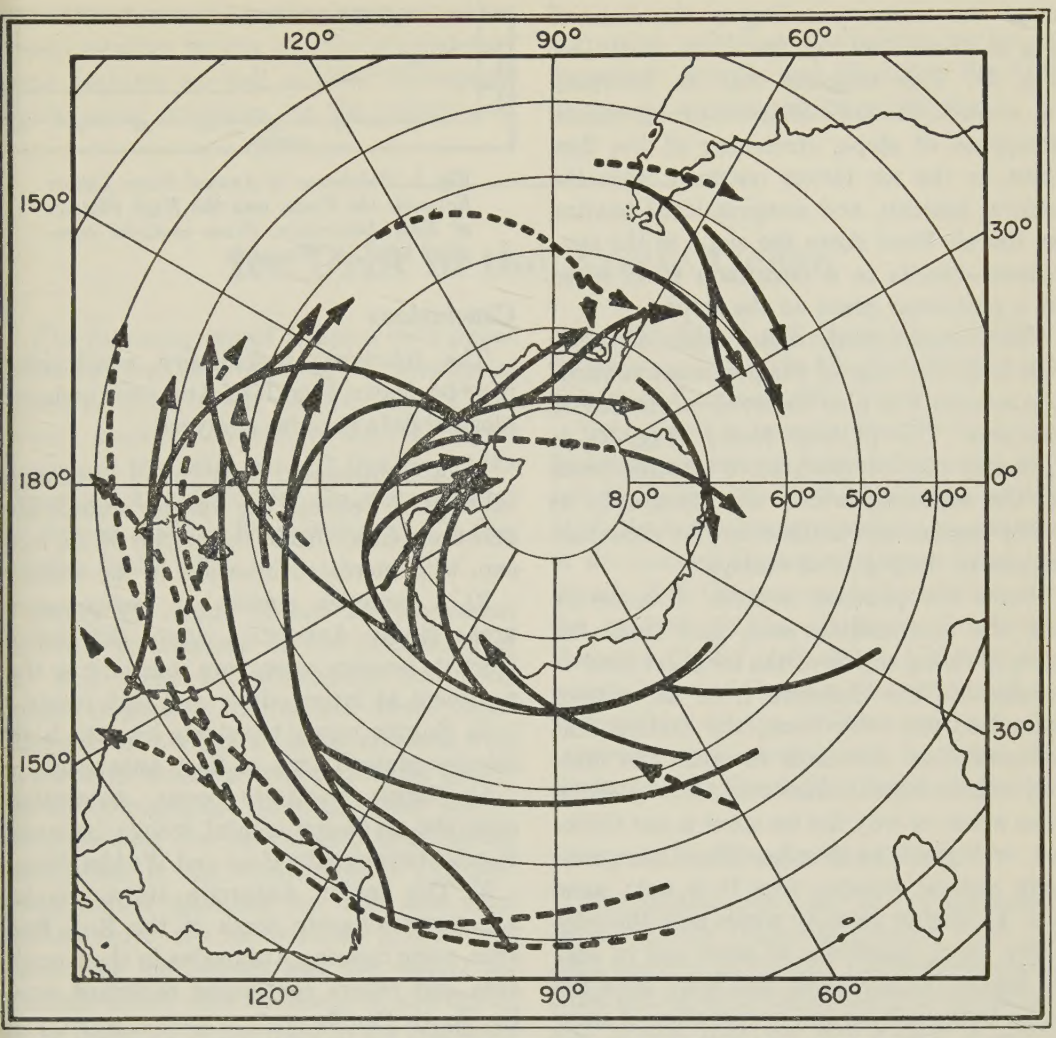

Fig. 1. *Tracks of Surface Systems in the Antarctic Region, Winter 1957. Solid lines represent cyclonic systems, dashed lines anticyclonic. Compiled at IGY Antarctic Weather Central.*

may be of great significance to Southern Hemisphere forecasting.

Weather and the Shape of the Ice Sheet: A Soviet meteorologist has theorized that the persistence of weather features in particular areas, specifically, the blocking of the movement of cyclonic storms by ridges of high pressure, has favored the outward growth of the continental ice sheet at certain points. He also applied this idea to the distribution of sea ice outward from the edge of the continental ice sheet and finds that, near USSR Mirny Station, aircraft observations support his conclusions.

Data gathered at Soviet IGY stations in East Antarctica indicate that the most persistent strong winds are found far up the slope of the ice sheet, about ⅓ of the way between the coast and the central plateau. This results, no doubt, from the broad gravity out-flow of cold air from the high central plateau. These wind observations were supplemented by studies of the size and orientation of sastrugi (irregular snow-surface features formed by wind action).

In a Soviet glaciological traverse from the coast to the interior of East Antarctica, a progressive increase in the height of sas-

trugi was noted, reaching a maximum of 2½ m about 260 km from the coast (see Fig. 2). This suggests that an interplay of several factors—temperature gradient, steepness of slope, stretching of the flow lines as the air moves outward from the central plateau, and compressional heating as the air flows down the slope of the continent—results in a maximum wind speed at a particular place on the slope.

The characteristic distribution of snowfall from the edge of the continent towards the interior was also observed on the Soviet traverse. The pattern found (Fig. 3) is probably also representative of other parts of the continent where the topography is fairly regular and undisturbed by mountain chains or deep glacial valleys.

Since the primary sources of moisture are the surrounding seas, and since the steeply rising slopes of the ice sheet tend to precipitate the moisture from air masses forced to rise over them, the finding that accumulation decreases towards the interior seems logical. However, the question then arises of why the ice sheet is not thickest, or highest, at its edge. There are probably several reasons why it is not; some are: 1) Higher velocity winds near the edge carry large quantities of snow out to sea; 2) higher temperatures and more sunshine cause more melting and evaporation of snow near the edge of the continent than in the interior; and 3) seaward movement of the ice sheet is more rapid near the edge.

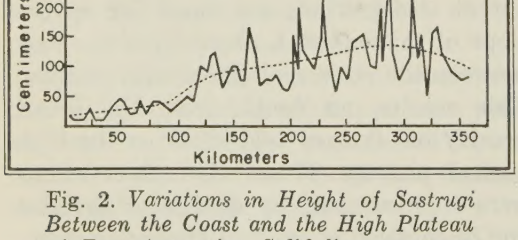

Fig. 2. *Variations in Height of Sastrugi Between the Coast and the High Plateau of East Antarctica. Solid line represents actual heights, dotted line represents average heights. The increase in sastrugi height toward the interior reflects the increase in wind speeds. From material compiled by P. A. Shumskii.*

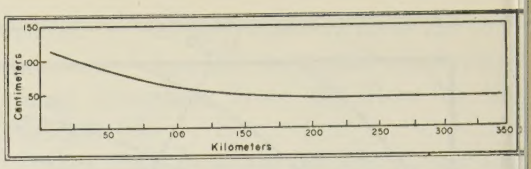

Fig. 3. *Thickness of Annual Snow Layers Between the Coast and the High Plateau of East Antarctica. From material compiled by P. A. Shumskii.*

Conclusions

The following preliminary conclusions may be drawn from IGY Antarctic meteorological data thus far analyzed:

1) A continuous, year-round exchange takes place between the warmer oceanic air and the cold air from the interior of the ice-cap, with increased intensity in the winter.

2) A complex system of low-pressure areas circles Antarctica about 300 miles from its borders, supplying warm air to the continent at intermediate and high levels.

3) Storms rarely penetrate into the high interior plateau area of East Antarctica.

4) Storms regularly cross Antarctica over the trans-continental trough believed to exist between the Ross and Weddell Seas.

5) The major Antarctic storm tracks appear to separate north of the Ross Sea area, some crossing Antarctica in the trough area and others continuing eastward over the South Pacific.

6) The "pole" of Southern Hemisphere circulation appears to be within an area of persistent high pressure over the high, central plateau of East Antarctica at some distance from the geographic South Pole.

7) There is a tendency for low-pressure areas to stagnate or to develop in the Ross Sea and Weddell Sea embayments.

8) The most persistent winds appear to exist over the icecap of East Antarctica about ⅓ of the distance between the coast and the high, central portion of the plateau.

IGY meteorologic data are also helping to outline mechanisms that may have brought about the present physical configuration of Antarctica. Obviously, there is

an intimate and complex connection between weather factors and the original geologic features as well as with subsequent glaciological processes. As the volume and scope of data from all three disciplines grow, a gradual unfolding of the long history of formation, growth, and change of the Antarctica ice mantle can be anticipated.

Ice Drift in the Arctic Ocean

The following report is based on a paper given by Irene M. Browne of the Geophysics Research Directorate, US Air Force Cambridge Research Center, at the IGY Symposium of the 125th Annual Meeting of the American Association for the Advancement of Science, held in Washington, D. C., December 29–30, 1958.

Study of Arctic Ocean ice movement provides information on the interaction of air and ocean not obtainable elsewhere, makes it possible to compare direct measurements of permanent ocean currents with concepts of these currents derived by analysis of hydrographic data, and may permit prediction of ice movement, thus aiding navigation in the Arctic Basin. The primary forces affecting ice drift are wind friction over the ice surface, friction between the ice bottom and the water, the Coriolis effect (the tendency of movement to be deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere, owing to the earth's rotation), and internal stresses within the ice itself.

Prior to the IGY, most data on Arctic Ocean ice drift were obtained by isolated expeditions (on some of which ships were intentionally allowed to become frozen into the ice pack), by Soviet drifting stations, and by a US scientific station on ice island T-3 (Fletcher's Ice Island, later the site of IGY Drifting Station Bravo). During the IGY, drift data were obtained mostly from scientific stations established on the floating ice. US-IGY Drifting Station Alpha was on a ten-foot-thick ice floe and Station Bravo is on Fletcher's Ice Island. (*Bulletins 1, 2, 6, 12, 16, 17,* and *22* contain additional information about the US-IGY drifting stations and their scientific programs.)

This report is based primarily on a preliminary survey of drift information obtained during the first 12 months of the IGY. Basic data were supplied by scientists of the Lamont Geological Observatory and Woods Hole Oceanographic Institution, under contract to the Air Force Cambridge Research Center, and of the Fisheries Research Board of Canada, who conducted investigations at the drifting stations; the analyses were carried out by Irene M. Browne at the Cambridge Research Center.

General Character of Ice Drift

The general character of ice movement in the Arctic Ocean is evident from the drift patterns of US and USSR drifting stations and of ships accidentally or intentionally frozen into the ice. Figure 4 shows some of these drifts.

The *Fram* Expedition of 1893–96, led by the Norwegian explorer-scientist Fridtjof Nansen, was the first major scientific expedition to the Arctic Ocean. Nansen permitted his specially-designed ship to be frozen into the pack ice on the Siberian side of the Arctic. In the next three years, during which many scientific studies were made, the *Fram* drifted with the ice pack completely across the Arctic Basin and was finally freed from the ice in the Greenland Sea, near Svalbard.

The Soviet ship *Sedov,* in a similar venture, was frozen into the ice in the same region in 1937. Its course paralleled that of

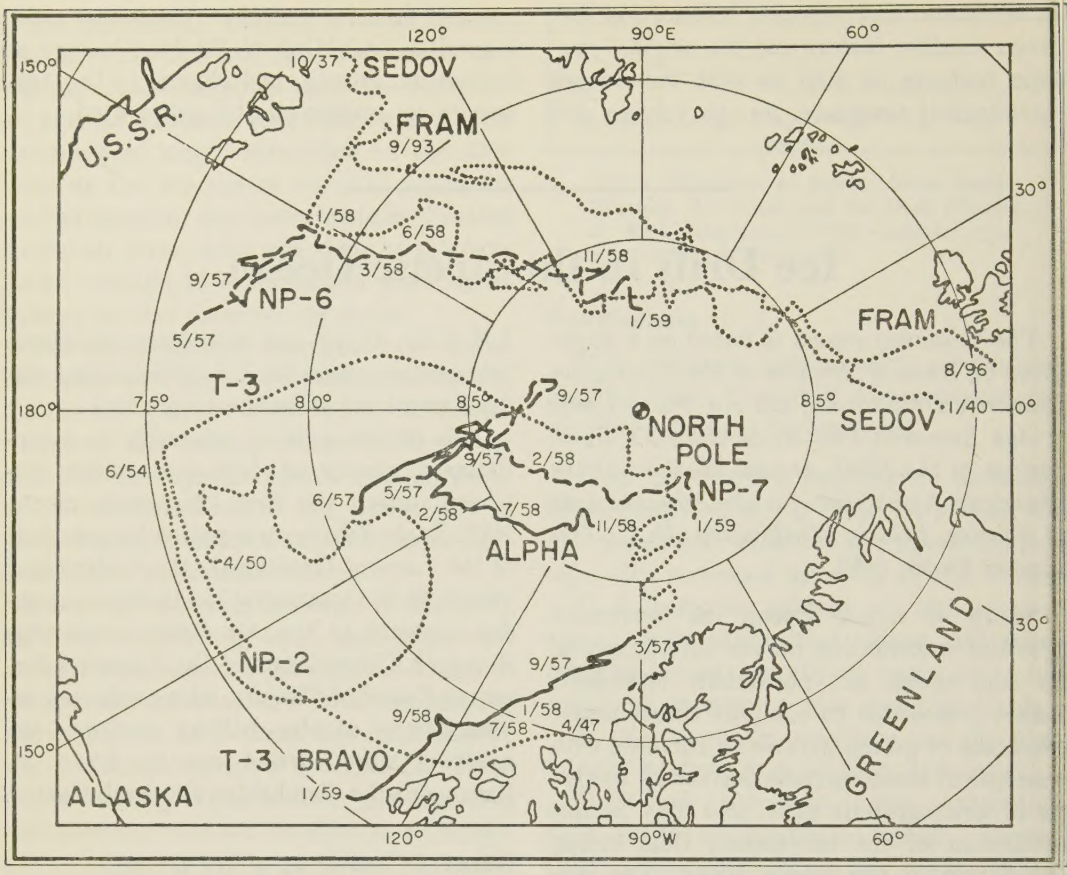

FIG. 4. *Arctic Ocean Drift Patterns. Solid lines represent drift paths of US-IGY stations, dashed lines paths of USSR-IGY stations, and dotted lines paths of pre-IGY stations or ships locked in ice.*

the *Fram*, thus confirming the drift pattern in that part of the Basin. Subsequent drifting-station studies by the Soviets further support the inference that the general movement on the Siberian side of the Pole is toward the Greenland Strait, with an accelerating speed. It takes about three years to complete the drift from the area of the Laptev Sea to Spitzbergen.

A clockwise pattern of drift on the North American side of the Pole was recognized by observations of the movement of ice islands T-1 and T-3 and confirmed later by the IGY drifting stations. In the vicinity of the Pole, movement is critical—either the ice may drift out with the Greenland current or back into another orbit. The time for circulation is about ten years.

If the ice moves into another orbit it is evidently subjected to intensive pressures, often resulting in breakup north of Canada and Greenland. Both North Pole 3 (one of the pre-IGY Soviet Drifting Stations) and US-IGY Drifting Station Alpha had to be abandoned in this region of ice convergence, and nearly half the drift cycles of ice islands T-1 and T-3 were spent in this area.

USSR-IGY Drifting Station North Pole 6, after an indecisive beginning is now drifting parallel to the *Fram* and *Sedov* courses. T-3 is moving southwest along the edge of the Canadian Archipelago.

The striking similarity of the drifts of Station Alpha and USSR-IGY Station North Pole 7 is immediately apparent (Fig. 4). Both stations were carried northward

until mid-September. The direction was reversed until mid-December and then the drift was in the general direction of Greenland. The distance between Station Alpha and North Pole 7 averaged 150 mi. The harmony of these drift patterns demonstrates quite distinctly the characteristic movement of the ice in this region.

Observations made thus far indicate that, in general, the ice drift follows closely the sea-level atmospheric pressure systems, that the clockwise orbit of ice movement on the North American side of the Arctic Ocean corresponds to the major motion of the surface currents, and that the rate of transport of surface waters and the rate of the observed ice drift in this region are on the same order of magnitude.

Wind Drift of the Ice

It appears certain from these IGY investigations that the main driving force for the drift of Stations Alpha and Bravo was the wind. When winds were strong and predominantly from one general direction, drift was relatively rapid and approximately before the wind (with some deviation to the right, as explained below). When winds were light and variable in direction, net movement was small.

Relationship to Atmospheric Pressure Systems: According to the Soviet theorist, Zubov, the Arctic Ocean ice pack moves parallel to the surface isobars (lines of equal atmospheric pressure); the higher pressures are to the right by about 1/100 of the geostrophic wind speed (wind deflection due to the earth's rotation). Figure 5 presents the mean sea-level pressure contours by quarters for the first twelve months of the IGY over the Arctic. Also shown are vectors representing the drift of the four stations during each period. Isobaric contouring in these high latitudes is subject to some error owing to the scarcity of meteorological stations, yet the conformity of the drift patterns to the pressure systems is evident.

In the first quarter, a low-pressure system situated north of the New Siberian Islands was responsible for the rapid northerly drift of Stations Alpha and North Pole 7. North Pole 6, located near the center of the low, and T-3, located between two pressure systems, were becalmed, as would be expected. The cyclonic system dissipated in the next quarter and was replaced by an intense high over the same general region. Correspondingly, the direction of ice movement was reversed, following the clockwise circulation of the anticyclone. This system persisted throughout the remainder of the 12-month period, during which North Pole 6 was in the region of strong trans-polar movement; Station Alpha and North Pole 7, after a period of southerly drift, were caught in a gradual movement toward the coasts of Canada and Greenland as the high moved across the Arctic Ocean; and T-3, first subjected to southeasterly flow, moved little during the rest of the period, when winds in general were shoreward.

Coriolis Effect and Drift Speeds: Beginning with the *Fram* expedition, it has been observed that the ice usually drifts to the right of the surface-wind direction in the Northern Hemisphere, owing to the Coriolis effect. Comparison of the predominant winds with the trend of Station Alpha's drift substantiates this observation. Over 90% of the drift angles (relative to wind direction) obtained for Station Alpha were oriented to the right of the surface-wind direction. The peak frequency is at drift angles between 30° and 50°, with a computed average of 33°.

Nansen first interpreted the deviation of the ice to the right of the wind as owing to the effect of earth's rotation. Later, V. W. Ekman provided a mathematical analysis which indicated that the angle of deviation of the surface current from the wind is 45°. The smaller value actually obtained for ice drift presents a problem. It has been attributed to internal ice resistance by some authors.

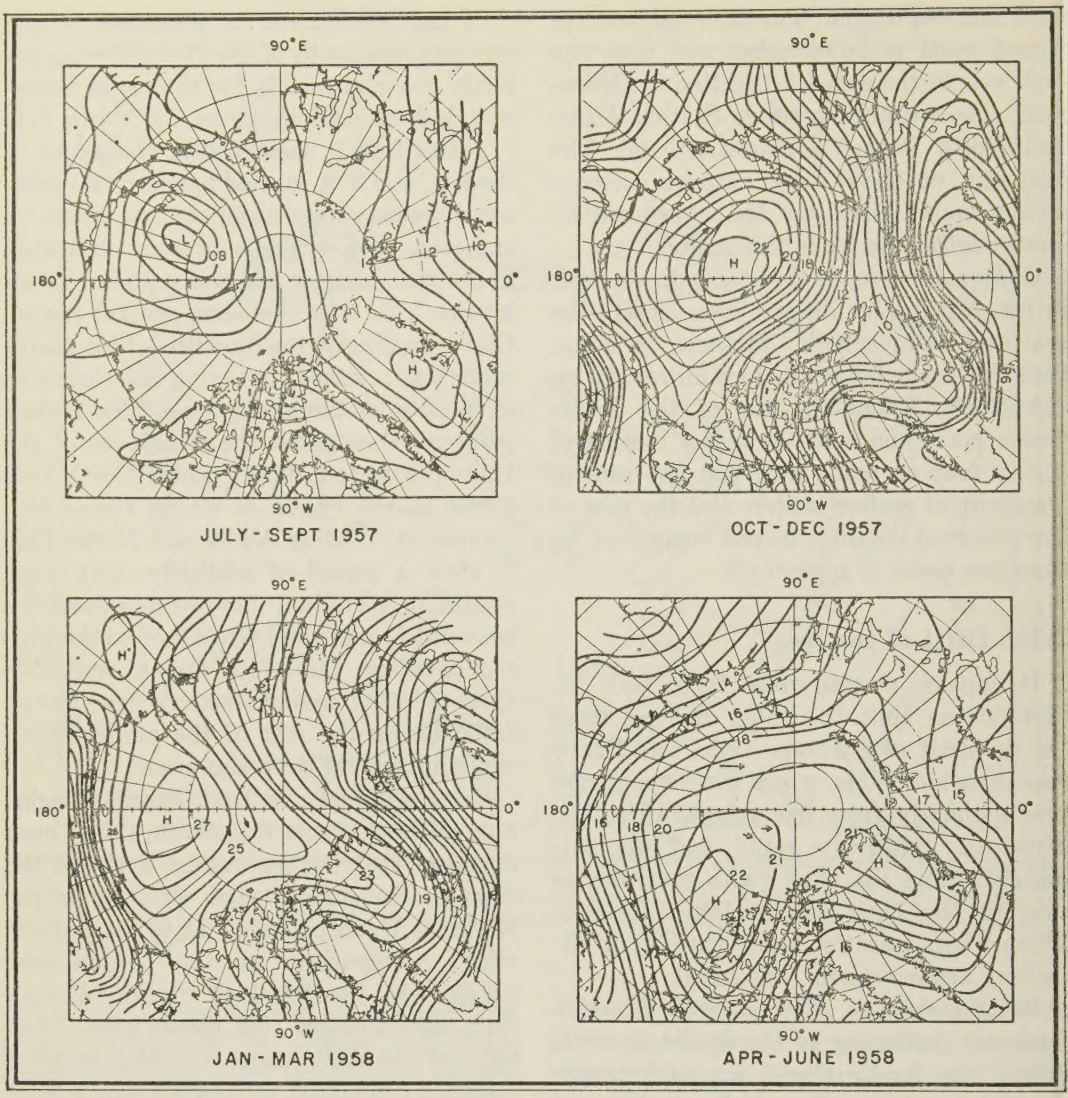

FIG. 5. *Sea-level Pressure Contours over the Arctic, by Quarters from July 1957 through June 1958. Pressures in millibars (for actual values, add 1000 to numbers above 00 and 900 to numbers below); arrows are vectors showing direction and relative amounts of ice movement.*

It was also found that over 60% of the time, the drift speed was 1/80th-1/40th of the surface wind speed. The average ratio was .0206, or about 1/50th.

The averages given above correlate well with the mean observations of angle deviation and drift-speed ratio found during the earlier expeditions, on which wind speeds were measured at heights of 6 or 8 m above the ice. A summary of these observations is given in Table 1.

TABLE 1

	Ratio of Ice Drift to Surface Wind Speed	Angle of Deviation of Ice Drift from Surface Wind Direction
Fram	.0182	28°
Maud	.0177	33°
Sedov	.0150	29°
T-3 (pre-IGY)	.0130	37°
Alpha	.0206	33°

The averages for the drift of T-3 are based on wind measurements at the higher

level of 10 m above the ice. Averages remained constant for both the pre-IGY and IGY movements of T-3, although there was a marked difference between the rate of movement in higher latitudes, where the ice is more closely packed, and in the regions of loosely packed ice nearer the coasts. In the higher latitudes, the island is locked tightly in the pack and is therefore strongly influenced by the rate of drift of the entire pack. Nearer the coasts, on the other hand, where the island is relatively free of the pack, its own large size probably has a greater effect on its movement.

Arctic Ocean Currents

Oceanic circulation must also be considered in analyzing the movement of the ice pack. The amount of hydrographic data for the Central Arctic is still limited but more is gradually being accumulated.

Hydrographic studies on Project *Skijump,* 1951–1952, indicated the existence of a giant eddy in the region north of Alaska (see *Bulletin No. 6*). The observed ice drifts conform to this circulation pattern. An analysis was made of the hydrographic data obtained from USSR drifting station North Pole 2, from ice island T-3 prior to the IGY, and from IGY Drifting Stations Alpha and Bravo. The results are given in Figure 6, which shows the dynamic height anomalies relative to the 600-decibar surface. (A decibar is the pressure exerted by a column of water one meter high. The dynamic height anomaly represents the deviation of the actual pressure surface from a level surface at the equivalent depth.)

If it is assumed that the 600-decibar surface is one of little or no motion, the surface-water movement will follow closely the contours of the sloping isobaric surfaces shown in Figure 6—the force of gravity moves the water down slope and the Coriolis force turns it to the right.

The addition of the IGY stations amplified knowledge of the circulation pattern and served to demonstrate that a closer contouring interval in the Alpha region and a more complex contouring in the T-3 area existed than previously thought.

The average rates of circulation in kilometers per year between certain hydrographic stations have been computed and are also shown in Figure 6. These rates give an average time of ten years for circulation around the outer edge of the eddy, which compares favorably with the observed drifts of ice islands T-1 and T-3. The rate of surface movement between Alpha hydrographic station 4 and *Skijump* (the pre-IGY program on ice island T-3) station 3 is calculated as 895 km/yr; between *Skijump* station 7 and North Pole 2 station 12 it is 554 km/yr. Over this same general area, ice island T-1 in 1947 and 1948, and Station Alpha during the IGY, traveled in approximately the same direction at the average rate of 650 km/yr, which compares very

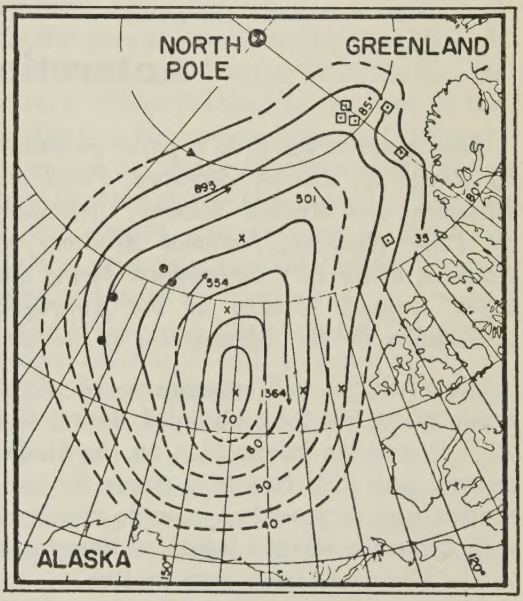

Fig. 6. *Dynamic Height Anomaly in Arctic Ocean North of Alaska, Showing Circulation Pattern. Dots are NP-2 hydrographic stations; crosses are* Skijump *stations; small dots in squares are Bravo stations; and triangle is an Alpha Station. Arrows and associated numbes show drift direction and rate (in km/yr) between certain stations. Contour numbers are in dynamic millimeters.*

well with the surface circulation computed from the available hydrographic data.

A small amount of current data was collected from Station Alpha. Analysis of these data shows that movement in the upper 16 m of the water corresponded to that of the ice in both speed and direction, with a small increase of speed with depth. Deeper current profiles and further information on daily ice movements were obtained during the summer of 1958. When analyzed, these data will help fill in the picture of water motion for this part of the Arctic Basin.

Statistical Investigations

In an effort to establish more clearly the nature of the forces affecting Arctic ice movement, certain statistical studies were made in addition to the direct measurements and comparisons already described.

Both drift-speed/wind-speed ratios and angle deviations observed along the Station Alpha drift path were examined statistically for trends indicating permanent current effects. None were found. Instead, a general scattering of the data was evident for all wind speeds. This is not surprising in view of the complexity of some of the factors involved in the drift of the Arctic Ocean ice pack. Principal among these is the transmission, over distances as great as 100 mi or more in the closely-packed ice, of internal stresses originating in areas of convergence and divergence.

Data collected during the IGY occupation of the drifting stations may eventually lead to a fuller understanding of this and other factors influencing drift patterns.

Antarctic Plant Life

This report is based on a paper presented by George A. LLano, Secretary, Panel on Biological and Medical Sciences, Committee on Polar Research, National Academy of Sciences, at the IGY Symposium during the 125th Annual Meeting of the American Association for the Advancement of Science.

Observations and specimens of Antarctic plant life were obtained during the IGY to provide information on the kinds, growth, and distribution of plants in Antarctica, and to provide a possible means of estimating the relative length of time some of the land areas have been ice-free.

Members of traverse parties from IGY Ellsworth and Byrd Stations made botanical collections in previously unknown areas of West Antarctica. During the summer 1957–58 resupply operations, George A. LLano took specimens from accessible coastal areas in the McMurdo Sound region and around the IGY Hallett and Wilkes Stations.

McMurdo Area

LLano's comparisons of the flora on Hut Point Peninsula (thin but widespread and persistent moss and lichen) with that at Cape Evans (no lichens and mosses, but plentiful fresh-water algae in shallow ponds) led him to the tentative conclusion that the Hut Point area has been free of ice for well over 500 years, while Cape Evans has been exposed for a relatively short time. Large colonies of lichens were found on Hut Point within one foot of the edge of the permanent ice fields, suggesting that the ice front is now stationary. Both locations are on Ross Island, near the US Naval Air Facility.

Ross Island is of volcanic origin, and its ice-free areas stand out like slag heaps. At both Hut Point and Cape Evans the dark volcanic rock is highly absorbent to solar radiation and hence provides favorable conditions for plant growth. The rock on the Cape, however, crumbles very easily under

frost conditions, and is an unstable substratum for the development of slow-growing plants, particularly lichens. Within the Hut Point area itself, the small orange-colored lichen *Placodium* grew in the pits of the larger lava blocks, but not in rocks that appeared easily shatterable by frost action. In general, such rocks were free of plants.

Another factor favorable to plant growth at Hut Point is that the mosses and lichens there were provided with essential moisture, available as meltwater from the surrounding ice fields, snow flurries, or blown snow. Moreover, during the brief open-water period, sodium compounds from sea spray undoubtedly served in lieu of the nitrogen compounds furnished by bird rookeries at other locations. The many small balls of sponge spicules found even on the higher inland slopes support this view.

Hut Point contained several varieties of moss and lichen in addition to the *Placodium*. Two species of the crustaceous lichen *Rinodina* were found on larger, smooth-faced black boulders. On higher flats receiving a slow flow of water-saturated material, small but thick pads of moss largely covered with the lichens *Physcia*, *Rinodina*, *Buellia*, and *Lecanora* grew in the lee of raised ground or small rocks.

The algae-loaded ponds at Cape Evans were found to be considerably smaller than when mapped by Scott in 1910; some had disappeared entirely. Their former shorelines could be traced by the remains of dried-out, colorless masses of algae.

Ponds at Cape Evans had little or no ice cover when those at Hut Point were still completely frozen over. In the frozen ponds at Hut Point, the alga *Phormidium incrustatum* was found imbedded. However, the plants did not remain frozen and dormant, as might be expected. Those projecting above the ice surface absorbed enough heat to form small pits around themselves and melt any snow that fell around them. The plants then took up the resulting moisture and apparently carried out photosynthesis, becoming soft, pliant, and deep green.

The *Rinodina frigida* found at Hut Point had a maximum diameter of 5 cm. In contrast, specimens up to 15 cm in diameter were seen above Taylor Dry Valley, 70 mi northeast, where they grew about 3000 ft above the valley floor, along a line that received daily snow flurries. To permit this large size, the substratum must have been ice-free for at least 1500 years.

Cape Hallett Area

The lichen vegetation on the summit of the headland near the joint US-New Zealand IGY Station at Cape Hallett, in East Antarctica, was luxurious out of all proportion to its surroundings. The summit, standing some 1500 ft sheer above Moubray Bay, consists of only 20-odd acres of bare land, almost completely hemmed in by massive ice fields. The ground is richly fertilized, however, owing to a rookery of 225,000 penguins (estimate by Carl Eklund, ornithologist and Station Scientific Leader at IGY Wilkes Station) at the base of the headland. A fine powder from the 1210-year-old guano deposit is raised by updrafts along the face of the slope to the summit. (The age of the deposit was determined by New Zealand scientists at IGY Hallett Station using carbon-14 techniques.)

The first lichens, bright-orange *Caloplaca*, always associated with guano deposits in polar regions, appeared some 200 ft above the rookery. Higher up, light-green *Neuropogon*, the only fruticose (shrub-like) lichen in East Antarctica, was encountered growing in mats like short grass. On the reddish volcanic rubble of the summit, *Umbilicaria* was a dominant element.

Wilkes Area

The area around IGY Wilkes Station was biologically the richest of all those investigated. The dominant lichen, *Umbilicaria*, was well represented by the cosmopolitan *Umbilicaria decussata*, which in temperate regions is commonly found only

in the alpine zone and then sterile. In the Wilkes area, however, the plant is ubiquitous and fertile. *Neuropogon* and a great variety of crustaceous forms were also present. Mosses occurred in small pockets of soil, and many of the marginal snowfields were reddish or green with algae.

The wide variety and extent of cryptogamic flora (not producing flowers or seeds) suggested that the land area around Vincennes Bay on which Wilkes Station is located, has been exposed for a long time. Other growth-accelerating factors also exist there, however—in particular, the tempering effects of the nearby sea, often ice free even in winter, and many seabirds.

Inland Regions

On the IGY Ellsworth Station Traverse during the Antarctic summer of 1957–58, N. B. Aughenbaugh, H. A. Neuburg, and P. T. Walker collected two specimens of lichens and one of a fresh-water alga in the Dufek Massif of the Pensacola Mountains, at about 82°S. The alga, *Phormidium incrustatum*, was the dominant plant growth in a shallow, 75-ft wide, fresh-water pond. Much of the algae lay exposed in dry windrows above the water level.

Both lichens were crustaceous species and, with the algae, are representative of genera having wide distribution in polar regions. Both were young, immature specimens, undoubtedly only recently established. One, a *Rhizocarpon*, was found on a large quartz pebble immersed under approximately a foot of water in the shallow end of the pond. The other, a *Caloplaca*, was taken from a crack in gabbro rock (dark igneous rock) next to a small, receding snowbank. This small detail of habitat emphasizes the dependence of these plants on moisture, and, therefore, the great importance of meltwater for plant growth. No other evidence of plant life in the Dufek Massif was found by the traverse party, but it seems probable that closer examination over a wider area would reveal other lichens.

Support for this belief is found in the extensive nature of the collections made in the Sentinel Mountains by D. P. Hale during the IGY Byrd Station Traverse of 1957–58. Hale collected some 60 species of lichens at a location (78°S) as far inland as that examined on the Ellsworth Traverse and isolated from other ice-free areas by a vast plain of very thick ice. Lichen genera found included *Caloplaca*, *Blastenia*, *Rinodina*, *Buellia*, *Hormiscium*, *Alectoria*, *Rhizocarpon* and *Umbilicaria*. With the exception of the last-named, all are rock-encrusting species common to the mountain areas of temperate zones as well as to the Arctic and Antarctic regions. Hale found no mosses, which apparently are more restricted in distribution than lichens, and quite possibly are altogether absent from the interior of Antarctica. The rigorous climate of the interior is not a deterrent, however, to the growth of lichens, which undoubtedly appear on ranges and peaks as far inland as the edge of the Polar Plateau, although few in species, gradually diminishing in numbers and of dwarf size.

Conclusions

From the data thus far available, LLano draws these tentative conclusions:

1. It is not likely that flowering plants will be found in Antarctica, except at a few sites on the Palmer Peninsula, which reaches to about 62°S.

2. Non-flowering plants—algae, lichens and mosses—have a remarkably wide distribution throughout the ice-free land areas. However, the cryptogamic vegetation of West Antarctica, and especially of the Palmer Peninsula region, is far richer than that of East Antarctica.

3. Terrestrial and fresh-water algae are probably the most widespread element of the Antarctic cryptogamic flora. One species, *Phormidium incrustatum*, is found in all persistent fresh-water ponds. The wide distribution of this alga may be attributed to the far-ranging skua's habit of bathing in fresh-water ponds.

4. Lichens have the second widest distri

bution of all land plants and should be expected on all exposed land masses even deep into the interior.

5. Mosses appear more restricted in distribution but are common in coastal areas.

6. New plant colonies on exposed land may be brought about by some Antarctic birds, but many of the interior sites could not have been colonized by this means. However, the presence of birds and their nitrogenous deposits are important in accelerating polar-vegetation development.

7. With the exception of the short fruticose *Neuropogon* genus, the lichens of East Antarctica are all rock-, earth-, or moss-encrusting forms. Large, ornate forms common to the tundra of Arctic regions are conspicuously absent.

8. Cold is not the major inhibiting force limiting the establishment or growth of plants in the Antarctic. The cryptogamic vegetation is dependent upon a combination of insolation (direct solar radiation) and moisture, the latter not necessarily as seasonal precipitation. The addition of guano, as dust or through leaching, is a strong factor in growth.

9. Insolation during the light period of the austral summer builds up over the rocks and earth a shallow thermal layer which is quite independent of the ambient air temperature. During the growing season, the cryptogamic vegetation of the land exists under microclimatic conditions not too unlike those at comparable locations in temperate regions.

IGY Bibliographic Notes

This is the eleventh of a series of bibliographic notes on IGY programs and findings. The references are selected largely from an IGY bibliography under preparation in the Science and Technology Division of the Library of Congress.

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